THE CLIMATE OF SOUTH AMERICA.*

BY

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The chief controls of the climate of South America are (1) the triangular shape of the continent, which is broadest near the equator and narrows southward; (2) the lofty mountain ranges along the western border, and (3) the cold ocean current off the Pacific coast. The broadening of the land-mass near the equator and the absence of high mountains along the Atlantic coast expose the greater portion of the vast northern and northeastern sections of the continent to the influence of the northeast and southeast trades, and ensure a remarkable uniformity of climate, with very small temperature ranges, over this whole region. The narrowing of the land-mass towards the south prevents the strong seasonal variations in temperature which characterize the broader continental areas in corresponding latitudes of the northern hemisphere, as, for example, in the case of North America. North America, like South America, is open on the east to the influence of the Atlantic; but while this fact is of the greatest importance in the southern continent, where the trades are thus given free access into the interior, the absence of high mountains along our own Atlantic coast has much less effect, because our prevailing winds are offshore. The mountains along the west coast of South America provoke rainfall on their windward slopes, and form a clearly-defined barrier between the climates of the narrow Pacific coastal

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Reference may be made to the following articles by the writer, in which various additional facts in connection with the climate of South America are emphasized: "Meteorology in South America," *Science*, N. S., Vol. V, 1897, 523–525; "Water Surface Temperatures of Lake Titicaca," *ibid.*, Vol. VII, 1898, 28–29; "Climatic Contrasts along the Oroya Railway," *ibid.*, 133–136; "A Note on the South American Coastal Cloud," *ibid.*, 1898, 211–212; "A Winter Barograph Curve from the South Pacific Ocean," *Monthly Weather Review*, Vol. XXV, 1897, 484–485; "The Climatic Control of Occupation in Chile," *Journal of School Geography*, Vol. II, 1897, 289–292; "Climatic Notes made during a Voyage around South America," *ibid.*, 1898, 241–248, 297–311; "A Day in the Falkland Islands," *Journal of School Geography*, Vol. II, 1898, 49–56.

zone and those of the eastern slopes and plains. The cold Peruvian current is instrumental in giving the coast of northern Chile and Peru temperatures considerably below those which are common to their latitudes, and in contributing largely to the aridity of these countries.

South America lies between the mean annual isotherms of 40° and 80° Fahr. The northern and northeastern portions of the continent, down nearly to the latitude of Rio de Janeiro, are within the district enclosed by the mean annual isotherm of 80°. The cold Peruvian current deflects the isotherms strongly equatorward along the Pacific coast, especially between latitudes 30° south and the equator; while these same isotherms loop strongly poleward over the land. These deflections are much less marked towards the southern extremity of the continent. The equatorward deflection of the isotherms on the west coast results in giving places on that coast much lower temperatures than those of stations in corresponding, or even in much higher, latitudes on the east coast. Thus Lima, in latitude 12° south, has a mean annual temperature of 66.2°; while Rio de Janeiro, which is nearly on the tropic on the east coast, has a mean annual of 72.1°. Pernambuco, in latitude 8° south, also on the east coast, has a mean annual temperature of 78.4°. The mean annual temperatures on the Atlantic coast between latitudes 30° and 40° south are about 5° higher than those in corresponding latitudes on the Pacific coast.

The seasonal migration of the sun north and south of the equator involves some changes in the distribution of temperature over South America. The average position of the axis of the equatorial belt of high temperature ("mean annual heat equator") is on the immediate sea coast in northeastern Brazil. From here the line runs northwest, parallel with the coast of Guiana and Venezuela. In January the heat equator moves to about latitude 15° south, in Brazil; while in July it migrates northward beyond the limits of the continent. In the former month the isotherm of 50° crosses the southernmost extremity of South America; while the belt of highest temperatures, enclosed by the isotherm of 80°, covers eastern and southern Brazil, and extends well into Argentina. In the southern winter (July) the temperature gradient over South America is somewhat stronger than in summer (January); but the change in the value of this gradient is not nearly so considerable as it is over the northern continents. Thus it appears that the southern summer is not marked by excessively high mean temperatures, and the southern winter is moderate, even in the higher latitudes. In

July the isotherm of 30° is found somewhat south of Cape Horn; while the belt of highest temperatures (over 80°) is found along the northern and northeastern coasts.

The mean annual ranges of temperature are very small over all of South America. Over the northern portion of the continent, including Peru, northern Bolivia, and the greater portion of Brazil, the range is less than 10°. Over a considerable part of this same area the range is even less than 5°. South of the tropic and east of the Andes the ranges increase to between 30° and 40° in northern Argentina. In contrast with these larger ranges in the continental interior on the eastern side of the Andes, the mean annual ranges in Chile, on the other hand, are less than 20°. The whole of the narrow western coastal strip thus has a very moderate climate. Even in the higher latitudes the winters are very mild, and the summers distinctly cool. One of the most notable facts in connection with the temperatures of South America is the marked negative anomaly (– 10°) near the equator off the west coast, which is due to the cold ocean water from the Antarctic flowing along the coast as the Peruvian or Humboldt Current. The effect of this cold water upon the temperature of the continent is seen in the presence of a negative anomaly of more than 2° along the coasts of Chile and Peru.

Another interesting effect is the exclusion of coral polyps from the Galapagos Islands; while they live on similar islands in much higher latitudes farther west in the Pacific.

Over a portion of the coasts of Guiana and of eastern Venezuela the mean minimum temperatures average over 68°. The lowest mean minima are found in the interior, east of the Andes and south of latitude 20° south. Temperatures below 32° occur normally every winter over the highlands of the southern interior of Brazil, and thence southward over the interior of Argentina. The highest mean maxima (104°) occur in the northern portion of Argentina. All of the west coast has decidedly lower maxima. Throughout the mountainous region of South America, altitude controls temperature to a marked degree. Places situated far above sea-level —as, for example, Quito—enjoy "perpetual spring" temperature. On the high peaks, even on the equator, there is eternal snow. An interesting lesson in the effect of elevation above sea-level in modifying climate may be learned by any one who takes a trip up the famous Oroya Railway, from sea-level at Callao to a height of 12,178 feet at Oroya, passing on the way, at Galera Tunnel, a height of 15,665 feet—the highest point reached by any railroad in

the world. The first part of the journey is through fields of sugar-cane and cotton; at 5,000 feet a zone of fruit trees is passed through; at 10,500 feet there is a district famous for its potatoes, where little else is grown; above this the altitude is so great as to preclude the growth of anything but grass. At the highest point reached the snow lies on the mountain summits throughout the year, and the traveller may enjoy a snowstorm in the middle of summer (December–February). Farther along the railroad, in the valley of Oroya, farm produce is again seen growing. This whole succession of climates may be passed through in the short space of ten hours—an opportunity offered to the traveller nowhere else in the world.

For the mean of the year, the barometric equator (axis of the equatorial belt of low pressure) crosses South America closely along the line of the geographic equator, running north of it on the west coast. The central portion of the continent is under the control of the tropical high-pressure belt; while over the southern extremity the pressure decreases rapidly towards the South Polar region. The seasonal migration of sun and heat equator involves a sympathetic migration of barometric equator and tropical high-pressure ("horse latitude") belt. In January the barometric equator moves south to about latitude 15° south in Brazil; while the axis of the tropical high-pressure belt, which is interrupted over the continent, lies about along latitude 30° south in the Atlantic and latitude 35° south in the Pacific. In July the barometric equator lies along the northern coast, and the axis of the tropical high-pressure belt is also farther north than in January. Seasonal changes and mean monthly ranges of pressure are slight.

The prevailing winds are controlled by the pressure distribution just noted. The broad northern portion of the continent east of the Andes and north of the tropical high-pressure belt is in the trade-wind zone. Here the trades prevail, as a rule, throughout the year, except when the sun is overhead. They are then temporarily replaced by the equatorial belt of calms and rains, which migrates north and south over the northern portion of the continent, following the sun. The west coast within the trade-wind latitudes south of the equator has its own system of winds, which is under the control of the tropical high-pressure area of the Pacific. These winds blow from a southerly direction along the coast nearly to the equator. Coming from a high latitude, and blowing over a cold current, these are cool and drying winds. The winds of extra-tropical South America are also chiefly controlled by the tropical

high-pressure areas of the South Atlantic and South Pacific oceans. The former of these areas gives easterly and southeasterly winds over the lower latitudes of the eastern portion of the continent, and prevailing northwesterly winds in the higher latitudes. On the west coast strong southerly winds blow with trade-like regularity along the coast north of the Pacific anticyclone; while northwesterly winds prevail to the south of it. The seasonal migration of these areas of high pressure involves a corresponding shift in the wind systems under their control. In summer, when the high-pressure belt is farthest south, south and southwest winds prevail along the west coast between 30° and 40° south; while south of latitude 40° north and northwest winds predominate. In winter the winds between 30° and 40° south are variable, with some calms; while the west and northwest winds blow nearer the equator than in summer. Thus the latitudes occupied by the southerly winds are extended in summer, and those occupied by the northerly and northwesterly winds are extended in winter. The harbour of Valparaiso, although well enclosed towards the south, is open to the north. When a *norte*, the indraught from lower latitudes towards a cyclonic centre, blows, as it often does in winter, and with considerable violence, the vessels at anchor in the bay are obliged to steam or to be towed out into the open ocean in order to avoid being blown ashore. In corresponding latitudes on the east coast there is also a northward extension of the limits of the northwest winds in winter. In Argentina northeast, east, and southeast winds increase in summer, and north, northwest, and west winds in winter. South of the tropic, and directly in the lee of the Andes, winds are of light velocity, and calms are frequent; while farther east, at a greater distance from the mountains, the velocity increases, and strong winds are common. In the mountains the winds are much influenced by local topography.

Darwin first distinctly emphasized the essential features of South American rainfall. In the latitudes of prevailing westerly winds (trades) the eastern side of the continent and the eastern slopes of the Andes are well watered; while the western slopes are comparatively dry. In the latitudes of prevailing westerly winds the western slopes of the mountains have the most precipitation; while the eastern side is dry. The rainfall is considerable (60–80 inches and over) on the elevated windward coasts of the continent (Guiana, southeastern Brazil) within the trade-wind belts, as it is on the eastern slopes of the Andes and over an extended area along the River Amazon. Within the southeast trade belt there is notably

less rainfall in the lee of the highlands of southeastern Brazil, and the rainfall also decreases rapidly in the interior over the more southern latitudes of this same belt, the country becoming almost a desert towards the eastern base of the Andes. The migration of the belt of equatorial calms and rains over the northern portion of South America involves a seasonal rainfall over the greater portion of the trade-wind latitudes. There is a dry season while the trade blows, and a rainy season while the equatorial rainy belt is overhead. This seasonal rainfall is well shown in the rainfall over the *llanos* of Venezuela and the *campos* of Brazil. The llanos have their rains during the northern summer, when they are under the equatorial rainy belt. During the rest of the year they are dry, when the sun is south and the trades blow across them. The *campos* of Brazil likewise have their rain in their summer (October–April), when the sun is south of the equator; while dry weather prevails during their winter, when the trades blow. The coasts of Guiana and Pernambuco and Bahia have winter rains. These rains are heavy, and are due to the onshore winds and the presence of high land near the coast. Pernambuco, situated just south of the extreme eastern point of South America, is exposed during most of the year to the strong southeast swell, produced by the southeast trade, and landing is therefore often very difficult.

The west coast within the trade-wind latitudes, from about 4° to about 30° south, is very dry. It is shut off from the trades by the great Cordilleran ranges on the east, and has prevailing cool southerly winds. These southerly winds, the spiral outflow on the eastern side of the South Pacific barometric maximum, cooled by the cool ocean water over which they blow, are decidedly warmed when they flow over the warmer land, and thus become drying winds, their capacity for water vapour being increased as their temperature is raised, although the presence of a range of coast-hills near the sea, along the greater part of the west coast, obliges these southerly winds to climb, and the adiabatic cooling produced by their ascent is not carried far enough, under ordinary circumstances, to produce rain. The coast cloud is a very marked phenomenon more or less all along the coast north of Valparaiso. It extends inland ten or fifteen miles at the points where the writer was able to make personal observations on it, and its base is between 2,000 and 3,000 feet above sea-level. As long as the southerly winds and the cool ocean current follow the coast, so long is the coastal strip dry and barren. As soon as the winds and current turn offshore, the previously-barren shores become covered with

vegetation. Analogous examples are to be found on the west coast of North America and the west coast of Africa. Although it very seldom rains along the desert coastal strip, rain and snow fall on the mountains of Peru and Bolivia during the summer. North of latitude 3° or 4° south there is abundant rainfall from the equatorial rainy belt, reaching 160 inches a year on the coast of Colombia north of the equator. Guayaquil has its rainy season from December to May. Near the west coast the migration of the equatorial rain-belt produces two rainy seasons when the sun is overhead, and two dry seasons when the sun is north and south. Quito and Bogotá have this double maximum of rainfall. Within the latitudes of the prevailing westerly winds the rainfall reaches over 80 inches annually along the southern coast of Chile. East of the Andes, over much of the pampas of Argentina and Patagonia, the average is under 10 inches. Towards the southern extremity of the continent the rainfall east of the mountains increases again, reaching 40 inches a year in the extreme southeast. In southern Patagonia the barrier on the west, owing to the diminishing heights of the mountains towards the south, is less effective than farther north. Furthermore, there is also a considerable precipitation from winter cyclones, whose influence extends over the low-lying Patagonian coast from the neighbouring Atlantic.

There is a seasonal distribution of rainfall in Chile, which depends upon the migration of the tropical high-pressure belt. Northern Chile, north of about latitude 30°, is always dry. Here is the desert of Atacama. Southern Chile has rain throughout the year, because it is always under the régime of the prevailing westerly winds. In the central portion there are rains only in winter, when the westerlies blow on that coast. The great climatic interest of the west coast of South America lies in the contrasts between the heavy rainfall on the southern coast of Chile, the intermediate barren desert belt of northern Chile and Peru, and the heavy rainfall on the coast north of Cape Blanco and Pt. Pariña, the westernmost point of the continent. These differences in rainfall have a close analogy in the rainfall on the west coast of North America.

So far as observation goes, no tropical cyclones originate in the South Atlantic, and all of equatorial South America is free from them. Cyclonic storms are, however, very common in the latitudes occupied by the prevailing westerly winds. The passage of such cyclonic storms across Argentina causes marked changes in wind, temperature, and weather. The warm, damp northerly wind (*norte*) in front of these depressions is followed by the cool, dry *pampero*

from the southwest, on the rear. The *pampero* corresponds in general to our own northwest wind, which is the rear indraft into a cyclonic centre. It is usually cool, dry, and bracing. The exclamation attributed to the first Spanish arrivals in this region, "*Que buenos aires son estos!*" must have referred to the conditions which prevail with a southerly wind, and not to those which the *norte* brings. The name *Buenos Aires* perpetuates, as is often the case with geographical names, a climatic feature of the region in which the city lies. Thunderstorms are most frequent over the northwest coast, as far as latitude 4° south, and occur in considerable numbers over all of South America within the tropics, except on the west coast, south of latitude 4°. The violent summer thunderstorms of the Argentine and of Uruguay often do serious damage to shipping in the Rio de la Plata estuary. The strength and the steadiness of the cyclonic-bearing westerly winds around the southern extremity of South America usually make the voyage around Cape Horn from the east very stormy and tedious; whereas vessels passing the Horn from the west usually have fair winds. The Strait of Magellan is used by all steamers which have to go around the southern end of South America; while sailing vessels are obliged to round the Horn, owing to the narrowness of the Strait and the difficulties of navigation through it.

Following Supan, South America may be divided into six climatic provinces. The first ("Tropical Cordilleran") includes the extreme northwestern section (the coasts of Colombia and Ecuador), with "perpetual spring" climates at high altitudes; high temperature near sea-level, and tropical rains. The second ("South American Tropical") takes in the vast northern and northeastern territory east of the Andes, and reaches somewhat south of the tropic. This is under the control of trades and of equatorial rains, and has mean annual temperatures over 80°. The third ("Peruvian") extends along the Pacific coast to 30° south, including northern Chile. This province is abnormally cool and rainless. The "North Chilian" province adjoining it on the south has a sub-tropical climate, with winter rains. Further south, the "South Chilian" province takes in the extreme southern extremity of the continent, is very rainy, and has equable temperatures throughout the year, with cool summers. The sixth ("Pampa") province, which includes the section east of the Andes and south of the "Tropical" province, has a fairly large range of temperature, especially in the north; while rain is not plentiful.